553-90

309533

N91-14173

Ar/S

Marshall L. McCall and Chris Stevenson
York University
Toronto, Ontario, Canada

and

Douglas L. Welch
McMaster University
Hamilton, Ontario, Canada

Summary

Near-infrared spectroscopy at high altitude and low humidity has been carried out to accurately measure [Ar III]λ7136 and [S III]λ9069 in the extreme metal-poor dwarf irregular galaxy IZw18. The ratio of the abundance of argon to the abundance of sulphur is within about 0.2 dex of the value for the solar neighbourhood. Since $n(\mathrm{Ar})/n(\mathrm{S})$ appears to be a universal constant, the line ratio [Ar III]λ7136/[S III]λ9069 may be a useful diagnostic of temperature in cool, metal-rich HII regions.

Background

For most HII regions with temperatures below about 8000 K, in particular metal-rich objects, standard temperature-sensitive lines such as [O III]λ4363 are too weak to be detected in reasonable exposure times. As well, the sensitivity of auroral lines to temperature fluctuations compromises their value. Abundances have therefore been estimated indirectly through modeling the ratios of the stronger, primarily optical, observable lines. Considering the complexity of the objects, the number of free parameters in the models, and the small number of lines available, these abundances are very uncertain. The problem is particularly important because of the ubiquity of low-temperature giant HII regions in spiral galaxies, which play a pivotal role in studies of abundance gradients and chemical evolution.

In fact, it may be possible to observationally check the model abundances for cool HII regions by adopting a universal value for the ratio of the argon abundance to the sulphur abundance. To a good approximation,

$$\frac{I([\mathrm{Ar\ III}]\lambda7136)}{I([\mathrm{S\ III}]\lambda9069)} = 2.03\,t^{+0.09}\exp(-0.453/t)\frac{n(\mathrm{Ar}^{++})}{n(\mathrm{S}^{++})}$$

where $n(\mathrm{Ar}^{++})$ and $n(\mathrm{S}^{++})$ are the number densities of doubly-ionized argon and sulphur, respectively, and where t is the electron temperature of the gas in units of 10^4 K (McCall, M. L. 1984, M.N.R.A.S., **208**, 253). The ionization potentials for Ar^+ and Ar^{++} are 2.0 and 3.0 Ryd, respectively, close to the ionization potentials of 1.7 and 2.6 Ryd for S^+ and S^{++}, respectively, so the Ar^{++} and S^{++} zones largely overlap. As a result, $n(\mathrm{Ar}^{++})/n(\mathrm{S}^{++})$ should be relatively insensitive to ionization structure, and, thus, directly related to $n(\mathrm{Ar})/n(\mathrm{S})$, particularly in low-excitation nebulae where little of the argon or sulphur is triply ionized. If $n(\mathrm{Ar})/n(\mathrm{S})$ is a constant, then the equation shows that the near-infrared line ratio should be a useful temperature diagnostic below 10,000 K. Most

importantly, the fact that the lines arise from upper levels with relatively low excitation potentials means that they remain fairly strong at low temperatures. The weak sensitivity to reddening is also a virtue. Whatever dependence there is on the ionization structure can be investigated (and corrected, if necessary) by studying correlations with [S III]/[S II] or [O III]/[O II] at fixed metallicity.

Both sulphur and argon are believed to be formed during explosive oxygen and silicon burning in massive stars. Since the two elements are synthesized under identical circumstances, it is reasonable to expect that $n(\mathrm{Ar})/n(\mathrm{S})$ should vary little from place to place in the universe. Indeed, it has been proven that the ratio varies by only about 0.05 dex from the Sun to the SMC, i.e. over a range of a factor of seven in the oxygen abundance. (Dufour, R. J. 1984, in *IAU Symp. 108: Structure and Evolution of the Magellanic Clouds*, eds. S. van den Bergh and K. S. de Boer (Dordrecht: Reidel), p. 353).

The authors are conducting an extended study of near-infrared argon and sulphur lines in extragalactic HII regions in order to verify the constancy of the abundance ratio and to evaluate its sensitivity to ionization details in order to derive metallicities of metal-rich giant extragalactic HII regions. Here, observations of IZw18 are presented in order to extend measurements of $n(\mathrm{Ar})/n(\mathrm{S})$ down to a metallicity more than a factor of forty below that of the solar neighbourhood.

Observations

Near-infrared CCD spectra of IZw18 were acquired at an altitude of 4200 meters with the Canada-France-Hawaii Telescope, while the relative humidity was 10%. A metal-poor red giant close in the sky was monitored during the observations in order to correct for the remaining atmospheric absorption. At this altitude and humidity the water vapour features that normally affect [Ar III]λ7136 and [S III]$\lambda\lambda$9069, 9532 are exceedingly weak. A total exposure of 3.3 hours over two nights led to the detection of [Ar III]λ7136 and [S III]λ9069. Reductions were carried out using IRAF, and measurements were made using software developed previously (McCall, M. L., Rybski, P. M., and Shields, G. A. 1985, Ap. J. Suppl., **57**, 1).

Results

The final observed and reddening-corrected relative emission line intensities are listed in Table 1., the latter obtained by assuming $E(B-V) = 0.17$ (Dufour, R. J., Garnett, D. R., and Shields, G. A. 1988, Ap. J., **332**, 752). The ratio $I([\mathrm{Ar\ III}]\lambda7136)/I([\mathrm{S\ III}]\lambda9069)$ is 0.31 ± 0.08. From the strength of [S III]λ6312 measured by Dufour, Garnett, and Shields (1988), the temperature of the S^{++} zone is of the order 18,000 K, which is consistent with O^{++} temperatures reported in the literature. Thus, the equation yields $n(\mathrm{Ar}^{++})/n(\mathrm{S}^{++}) = 0.19 \pm 0.05$. An O^{+} temperature of $(14,300 \pm 3400)$ K is derived from our measurement of [O II]$\lambda\lambda$7320, 7330 and the average published value for [O II]$\lambda\lambda$3726, 3729. Based upon models by Dufour, Garnett, and Shields (1988), the ionization correction factor $X(\mathrm{Ar}^{++})/X(\mathrm{S}^{++})$ is 0.5 to 0.7, so $n(\mathrm{Ar})/n(\mathrm{S})$ is 0.40 ± 0.10 to 0.26 ± 0.07. Referencing to the Sun, $[\mathrm{Ar/S}] = 0.07 \pm 0.12$ to 0.26 ± 0.11. The result seems to confirm the view that nucleosynthesis of argon goes hand in hand with sulphur, and gives further impetus to the employment of the abundance ratio to probe the temperatures of metal-rich nebulae.

Table 1

Relative Line Intensities for IZw18

line	wavelength	$F(\lambda)/F(\mathrm{H}\alpha)$	$F(\lambda)/F(\mathrm{H}\beta)$	$I(\lambda)/I(\mathrm{H}\beta)$[1]
[O II][2]	3727Å	—	—	31.9±5.6
He I	5876Å	2.164±0.100	7.27±0.34	6.27±0.29
[S III][3]	6312Å	—	0.9±0.8	0.7±0.6
Hα	6563Å	100	336	277
He I	6678Å	0.865±0.073	2.91±0.25	2.38±0.20
[S II]	6723Å	1.054±0.088	3.71±0.30	3.02±0.24
He I	7065Å	0.663±0.100	2.23±0.34	1.77±0.26
[Ar III]	7136Å	0.389±0.088	1.31±0.30	1.04±0.23
[O II]	7326Å	0.396±0.100	1.33±0.34	1.04±0.27
[S III]	9069Å	1.438±0.216	4.83±0.73	3.40±0.51

[1] Corrected for reddening $E(B-V) = 0.17$.

[2] Average of values as reported from the literature by Davidson,K., and Kinman,T.D. 1985, *Ap. J. Suppl.*, **58**, 321.

[3] Dufour,R.J., Garnett,D.R., and Shields,G.A. 1988, *Ap. J.*, **332**, 752.